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Original Article

AI in critical care: A narrative review of prospective applications and future potential in KSA's health transformation 2030

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الملخص

يعتبر استخدام الذكاء الاصطناعي في طب الرعاية الحرجة في المملكة العربية السعودية من أهداف ومبادرات التحول الصحي السعودي المستسقاة من أهداف رؤية المملكة العربية السعودية 2030. كجزء من برنامج تحول القطاع الصحي، يهدف دمج تقنيات الذكاء الاصطناعي إلى تحسين نتائج المرضى، وتحسين سير العمل، وتحسين الكفاءة التشغيلية لوحدات العناية المركزة. تشمل التطبيقات الرئيسية التوثيق السريري الآلي، والتحليلات التنبؤية للكشف المبكر عن التدهور السريري، وتقنيات التصوير بمساعدة الذكاء الاصطناعي، مثل قراءة الأشعة السينية للصدر والموجات فوق الصوتية. لا تدعم هذه الابتكارات الأطباء من خلال تقليل العبء الإداري عليهم فحسب، بل تمكنهم أيضا من التدخل في الوقت المناسب لاسيما في بيئات العمل محدودة الموارد. بالإضافة إلى ذلك، يتم استكشاف مراكز قيادة وحدة العناية المركزة عن بُعد المدعومة بالذكاء الاصطناعي كوسيلة لتوسيع نطاق خبرة الرعاية الحرجة إلى جميع مناطق المملكة العربية السعودية وتعزيز الوصول العادل إلى الرعاية المتخصصة. يلقي هذا البحث الضوء على إمكانات الذكاء الاصطناعي لإعادة تشكيل عمليات وحدة العناية المركزة، وتعزيز عملية صنع القرار، ودعم رؤية المملكة العربية السعودية لنظام رعاية صحية متقدم قائم على التكنولوجيا.

الكلمات المفتاحية: الذكاء الصناعي؛ العناية المركزة؛ التحول الصحي السعودي

Abstract

This narrative review explores the integration of artificial intelligence (AI) within critical care settings in KSA in alignment with the goals outlined in Saudi Vision 2030. As part of the Health Sector Transformation Program, the incorporation of AI technologies aims to enhance patient outcomes, optimize workflows, and improve the operational efficiency of intensive care units (ICUs). Key applications include automated clinical documentation, predictive analytics for early detection of clinical deterioration, and AI-assisted imaging techniques, such as chest X-ray and ultrasound interpretation. These innovations can support clinicians by reducing their administrative burden as well as enabling timely interventions, particularly in resource-constrained environments. In addition, AI-powered tele-ICU command centers are explored to extend critical care expertise to underserved regions and enhance equitable access to specialized care. This review was conducted using a structured narrative approach by synthesizing peer-reviewed literature, national policy documents, and expert perspectives from ICU physicians in KSA, Canada, and other international settings.

Keywords: Artificial intelligence; Critical care; ICU; Saudi health transformation

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Introduction

Saudi Vision 2030 outlines a transformative framework aimed at enhancing quality of life, driving economic diversification, and advancing national development. A key pillar of this vision is the modernization of KSA's healthcare sector to ensure equitable, efficient, and high-quality medical services for its population of over 33 million people. The Health Sector Transformation Program, one of the Vision Realization Programs, is central to these efforts, emphasizing the integration of digital health solutions, artificial intelligence (AI), and data-driven decision making to improve healthcare accessibility and clinical outcomes.[1]

KSA has already made major strides in digital health innovation through platforms such as Seha Virtual Hospital, Sehhaty, and Mawid. Seha, launched in 2022, connects over 220 hospitals and has become the world's largest virtual hospital, offering remote consultations and subspecialty services at scale.[2] Sehhaty and Mawid support appointment scheduling, virtual triage, and access to test results, expanding the reach of healthcare beyond traditional hospital infrastructure.[3]

Despite these achievements in general healthcare access, critical care medicine presents unique challenges that demand targeted innovation. Intensive care units (ICUs) are among the most complex and resource-intensive environments in modern healthcare, requiring continuous monitoring, rapid interventions, and highly specialized medical expertise to manage critically ill patients.[4] These environments generate massive streams of real-time data ranging from vital signs and ventilator settings to laboratory trends and imaging results, which must be rapidly synthesized to guide clinical decisions. Manually interpreting these data in real time imposes significant cognitive and operational demands on clinicians, contributing to potential delays in recognizing deterioration and increasing the risk of adverse outcomes.[5–7] This cognitive overload has been linked to increased error rates, burnout, and reduced responsiveness to early warning signs.[6,7]

AI-driven technologies provide promising solutions to these ICU-specific demands.[4,8] AI tools enable automated real-time data integration, predictive analytics, and clinical decision support to assist overburdened teams in managing complex ICU workflows. Applications include imaging interpretation through convolutional neural networks; predictive modeling for sepsis, acute respiratory distress syndrome (ARDS), and cardiac arrest; remote monitoring, and tele-ICU platforms to expand access and workflow automation for tasks such as documentation and staff allocation.[9–13]

As part of its healthcare transformation, KSA has implemented the Saudi Model of Care (MOC) as a framework designed to enhance patient-centered care across all healthcare levels.[14] A key priority of MOC is strengthening emergency and critical care services, ensuring that life-threatening conditions are identified and managed efficiently.[15]

AI-driven systems further optimize ICU operations by automating real-time patient monitoring, reducing clinician workloads, and ensuring continuous high-quality care, particularly in high-demand ICU settings.[16] In addition, AI-powered tele-ICU capabilities can extend critical care expertise to rural hospitals and understaffed medical centers, improving access to specialist consultations.[17] AI also enhances ICU resource management by automating documentation and optimizing the allocation of staff, equipment, and ICU beds.[18] Moreover, AI plays an essential role in early warning systems, detecting conditions such as sepsis, ARDS, and cardiac arrest before severe clinical deterioration occurs, enabling timely medical intervention.[11,19,20]

Given KSA's robust digital infrastructure and ongoing investment in AI-driven healthcare applications, the country is well positioned to lead the integration of AI in ICU settings.[21] To position KSA as a pioneer in implementing AI across ICUs, further research, validation, and refinement are needed to maximize its transformative potential. This narrative review explores how AI can address the unique challenges of critical care medicine, with a specific focus on its applications in ICU workflow automation, remote monitoring, predictive modeling, and imaging diagnostics.[22]

Materials and Methods

This narrative review was based on a targeted search of peer-reviewed literature and policy documents published between 2017 and 2025. Sources were identified using PubMed, Scopus, and Google Scholar with keywords such as "AI," "ICU," "critical care," "machine learning," and "KSA." Government publications, including Vision 2030 and Ministry of Health reports, were included to align with national healthcare priorities. Relevant articles were selected based on clinical applicability to ICU settings, with expert input from practicing intensivists in KSA and Canada to guide topic selection and ensure clinical relevance.

Intersection of the Saudi health transformation and AI in critical care

Revolutionizing ICU workflow and clinical documentation

AI-powered clinical documentation and decision support

Maintaining detailed clinical documentation is one of the most time-consuming aspects of ICU care, and it often diverts the attention of clinicians from direct patient management.[13,23] AI-driven natural language processing tools have the potential to address this challenge by automating real-time transcription and structuring of clinical notes, thereby reducing the administrative burden and improving the accuracy of documentation.[13,23] AI-enabled documentation systems can integrate seamlessly with electronic health record platforms, minimizing manual data entry and allowing clinicians to focus on critical decision making and patient care.[13] By streamlining record keeping and optimizing information retrieval, AI-powered documentation has the potential to improve the ICU workflow efficiency, ensuring that patient data are both accessible and actionable.[13,18,23]

AI-enhanced ICU command centers and remote monitoring

KSA's investment in smart hospitals and digital health solutions presents an opportunity to establish AI-driven ICU command centers, consolidating real-time patient data into a single, interpretable dashboard.[2] These AI-powered systems could assist in ventilator management, medication titration, and fluid balance optimization, ensuring evidence-based decision making in real time.[8,16] These systems have the potential to extend expert ICU support to hospitals with limited intensivist availability by integrating remote monitoring capabilities within centralized platforms. AI algorithms can analyze trends, detect deviations from baseline physiological parameters, and issue early alerts of physiological instability, assisting clinicians in making timely, evidence-based treatment adjustments.[10,17,24] By leveraging predictive analytics, these command centers could also anticipate workflow bottlenecks, optimize staff workload distribution, and enhance resource allocation. Based on this approach, AI has the potential to support a more proactive and scalable model of ICU care.

Early detection and prediction of clinical deterioration

AI-driven early warning systems and predictive models

AI-powered early warning systems have been demonstrated to detect subtle physiological changes that precede clinical deterioration by continuously analyzing real-time data, such as vital signs, laboratory trends, and ventilator settings.[9,11,12,25,26] Several validated models, such as DeepSOFA (deep learning), InSight (logistic regression and random forest), and eCART (ensemble-based), exemplify how AI is being operationalized in ICU prediction tasks.[19] These tools have exhibited superior performance compared with traditional scoring systems such as SOFA or APACHE in predicting outcomes such as mortality, septic shock, and ICU transfer.[6,7,11,12,27] Machine learning models can further enhance precision medicine by dynamically updating risk estimates as patient conditions evolve,[10,14,28,29] thereby supporting the judgments of clinicians by improving situational awareness and enabling more data-informed decisions.[18]

In resource-constrained ICU settings, early and accurate disease prognostication is critical for guiding clinical decisions. AI has the potential to support healthcare providers in making timely decisions regarding supportive care, do-not-resuscitate orders, and even withdrawal of care within hours of ICU admission. In particular, the Early Mortality Prediction for Intensive Care Unit Patients Random Forest model has exhibited superior performance in predicting mortality compared with standard scoring systems, where the area under the receiver operating characteristic (AUC) curve indicated higher accuracy. This model can provide reliable mortality predictions within the first 6 h of ICU admission, offering an opportunity for earlier, more informed discussions about patient care.[27] Importantly, the use of these predictive models is best framed as a supplement to clinician expertise, particularly when navigating ethically challenging decisions.[22]

Advancements in imaging and diagnostics

AI-assisted chest X-ray interpretation

Chest radiography is a cornerstone of diagnostic evaluation in critically ill patients, but timely interpretation can be challenging in high-volume ICUs.[30] Deep learning models, particularly convolutional neural networks (CNNs), have demonstrated promising performance in automating chest X-ray interpretation. Tools such as CheXNet, trained on the NIH ChestX-ray14 data set (containing over 112,000 images), have achieved AUC values of 0.96 for pneumonia and comparable performance to radiologists in detecting pneumothorax and pulmonary edema.[10] By expediting image interpretation and prioritizing abnormal findings for clinician review, AI can reduce reporting delays and ensure timely treatment, particularly in resource-constrained ICUs where radiologists are not readily available.[30,31]

AI-assisted lung ultrasound

Point-of-care ultrasound is essential for real-time pulmonary assessment in ICU patients. AI has been leveraged to enhance lung ultrasound interpretation, including detecting pneumothorax by identifying lung sliding. In one study, a CNN-based model obtained over 90% sensitivity and specificity in distinguishing the presence or absence of lung sliding using annotated ultrasound clips.[32] AI also supports the quantification and classification of B-lines, ultrasound artifacts indicative of interstitial fluid, enabling clinicians to more accurately assess pulmonary edema. Furthermore, models can differentiate between pleural effusions and consolidations, informing fluid management and drainage decisions.[33]

Cardiac ultrasound and echocardiography

AI-driven echocardiography has emerged as a valuable tool for bedside cardiac evaluation in unstable ICU patients. Deep learning algorithms can automatically estimate left ventricular ejection fraction (LVEF), evaluate diastolic function, and detect pericardial effusions, reducing the need for formal echocardiography in urgent settings. For example, the EchoNet-Dynamic model obtains strong correlations with expert measurements of LVEF (Pearson's $r = 0.92$) and can generate beat-to-beat predictions, improving the accuracy of hemodynamic monitoring.[34] These technologies can assist frontline clinicians with limited echocardiography training by providing automated interpretations that improve diagnostic confidence.[35]

AI-guided procedures

In addition to diagnostics, AI is being applied to procedural guidance in the ICU. Real-time ultrasound guidance powered by AI can improve the safety and accuracy of central venous catheter insertion, thoracentesis, and paracentesis. By detecting key anatomical landmarks and offering visual overlays, AI reduces the reliance on operator expertise and minimizes complications. Preliminary studies suggest that AI-guided vascular access systems can reduce needle passes and the procedural time, although further validation is needed before their widespread adoption.[36,37]

Abdominal ultrasound

Abdominal ultrasound is frequently employed in ICU trauma assessments and abdominal sepsis workups. AI tools are being developed to identify free intraperitoneal fluid[38] and assess bowel motility, particularly in patients with suspected ileus or mesenteric ischemia. Although still in the early stages, models trained on labeled ultrasound data sets have obtained high accuracy in identifying fluid pockets and peristalsis patterns, which may expedite diagnosis and guide interventions such as laparotomy or bowel rest protocols.[39]

Limitations and implementation challenges

There are considerable potential applications of AI in the ICU but several important limitations and implementation challenges must be addressed to ensure safe and effective deployment. One major concern is the risk of over-reliance on algorithmic outputs without appropriate clinical oversight, which may lead to misinterpretation or suboptimal decision making, particularly when models are used outside their validated context.[40] Even when accuracy metrics are high in research settings, real-world performance can vary depending on patient complexity, data quality, and workflow integration.[41] In addition, operator training is critical, especially for tools such as AI-assisted ultrasound, where successful implementation depends on the clinician's ability to acquire technically sound images.[40] Without this foundation, even advanced models may yield inaccurate results or add to the clinician burden. Moreover, most AI systems have been trained using data from Western, high-income healthcare settings, raising questions about their generalizability across diverse populations.[42] To address this issue, local validation studies will be essential in the Saudi context. Finally, integration with hospital infrastructure, including electronic medical records and picture archiving and communication systems, remains a key barrier.[41] National initiatives such as Seha Virtual Hospital provide a strong digital backbone but further investment in interoperability, standardized implementation, and governance frameworks will be necessary to support the scalable use of AI in critical care.[43]

Conclusion and recommendations

The integration of AI into intensive care represents a transformative opportunity for KSA as it advances toward the goals of Vision 2030.[1] This review summarizes the possible applications of AI in critical care, including early detection of clinical deterioration,[20,25,26,28] automation of documentation,[13,23] advanced imaging interpretation,[26–35] and remote monitoring through tele-ICU systems.[17,28,29] These technologies have already proved valuable in improving workflow efficiency,[16] enabling earlier clinical interventions,[19] and supporting equitable access to specialized care.[17] Thus, they align with national priorities to improve quality, efficiency, and equity in healthcare delivery.

Despite these potential applications, several implementation challenges remain. Many AI models have been developed mainly using data from Western settings, which may limit their accuracy in KSA's diverse clinical environments.[42] Risks such as algorithmic bias, lack of transparency, overreliance on AI recommendations, and data privacy concerns must be managed through rigorous validation, ethical oversight, and clear regulatory guidance.[43] Technical challenges also persist, including integration with electronic medical records and imaging systems, as well as the need for consistent data standards.[41] At the clinical level, many healthcare professionals may lack the training to use AI tools confidently or interpret their outputs appropriately.[40]

To support safe and scalable implementation, national strategies should emphasize the need for structured and inclusive deployment supported by strong governance. AI models should be validated using local patient data to ensure relevance and reliability. Policies must promote interoperability and seamless integration into clinical systems, while also safeguarding privacy and security. Equally important is investment in clinician education. Clearly, ICU physicians, nurses, and allied staff must be equipped with the skills to use AI tools safely and effectively, and their feedback should guide how these technologies are adapted for the local context. Further research will be essential to guide responsible scaling. In particular, prospective clinical studies, real-world evaluations, and post-implementation audits are needed to assess the performance of AI in local ICUs and build an appropriate evidence base to support continued adoption.

KSA is well positioned to become a global leader in the application of AI in critical care due to its strong digital infrastructure, growing investment in innovation, and commitment to healthcare transformation. By focusing on locally informed, ethically sound, and clinician-led implementation, AI can be used to enhance patient care as well as to build a more proactive, efficient, and equitable critical care system across the Kingdom.

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The authors have no conflicts of interest to declare.

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Consent

Not applicable.

Authors' contributions

All authors contributed to the conception or design of the work, drafting the manuscript, and critically reviewing and approving the final draft, and they are responsible for the content and similarity index of the manuscript. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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